Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 45 (2015) 602 – 610

Procedia Computer Science

International Conference on Advanced Computing Technologies and Applications (ICACTA-2015)

Performance Analysis of a Computer System with Imperfect Fault Detection of Hardware

Ashish Kumar[a*], Monika Saini[b], S.C. Malik[c]

[a,b] Department of Mathematics & Statistics, Manipal University Jaipur, Jaipur-303007, India

[c] Department of Statistics, M.D. University, Rohtak-303007, India

Abstract

The purpose of the present work is to evaluate the functioning of a computer system using the concepts of imperfect fault detection of hardware parts and up-gradation of software upon their failure. A stochastic model for a data processor system consisting of two identical units- one is operative and the other kept as a standby is developed. A single repair facility is supplied to the system which plays the double function of the sensor as well as a maintenance man. Upon failure of the detector to detect the fracture of the hardware component unit immediately replaced by the maintenance man. Nonetheless, only up-gradation of the software is made upon failure. All time distribution except failures follows an arbitrary distribution while failures are exponentially dispersed. The expressions for several reliability measures are derived by making use of semi-Markov processes and regenerative point of technique. Numerical results are drawn from a particular case to highlight the importance of the study.

Peer-review under responsibility of scientific committee of International Conference on Advanced Computing Technologies and Applications (ICACTA-2015).

Keywords: Hardware and Software Failures, Detector, Hardware Replacement, Software Up-gradation and Performance Analysis.

2000 Mathematics Subject Classification: 90B25 and 60K10

1. Introduction

One of the most critical competitive factors in the computer systems market is the reliability of the system, given that the simplest component failure may stop entire system. Applications of computer systems are pictured in every sphere of human lifespan. In the same line, banking organization, education organization, military, space projects and medical systems are intolerant of failures, as the economy and lives may depend on the reliable operation of the computer systems. In scientific or industrial sector failures of computer systems results in terms of downtime of the arrangement. Thus, computer systems must be planned to work continuously for years without breaks. To conform to these higher quality demands of the industry and consumer marketplace, it is called for sophisticated testing processes and new performance evaluation techniques which provide a company the capability

Peer-review under responsibility of scientific committee of International Conference on Advanced Computing Technologies and Applications (ICACTA-2015).

doi:10.1016/j.procs.2015.03.114

to see how their plan would hold up over the years, without having to wait that long. Withal, to conceive of a system without failure is rather unacceptable. Infect, a Computer system exhibits two types of failures- hardware and software. But this does not entail that the computer system cannot be made authentic.

A number of researchers and scientists from the infant age of computer systems are trying to improve the performance and reliability of computer systems. First of all, Bouricius et al[3] designed the reliability modeling techniques for the computer systems. Arnold[2] discusses the concept of coverage and its effect on the reliability of repairable systems. Sahner et al[4] discusses the performance and reliability of computer systems with an example based approach using SHARPE software. Amari et al[1] designed a stochastic model for optimal reliability with imperfect fault coverage. Recently, Welke et al.[6], Lai et al.[7] and Freedman and Tran[5] tried to design stochastic models for computer systems with hardware and software components. Kumar and Malik[9] and Kumar et al.[12] have proposed reliability models on computer systems with hardware and software failures. Malik and Anand[8] suggested a stochastic model for the economic analysis of a computer system with independent hardware and software failure.

It is already established in previous research that preventive maintenance can slow the worsening process of a repairable system and restore the system in a younger state. Kumar et al.[11] studied the effect of preventive maintenance on computer systems with independent hardware and software failure. Kumar and Malik[10] carried out the cost-benefit analysis of computer systems with conducting preventive maintenance after maximum operation time. Kumar and Malik[13] developed a reliability model for a computer system by using the concept of priority to hardware repair over replacement of the hardware components. Recently, Malik and Munday[14] suggested a stochastic model for computer systems with the provision of redundant hardware component. But so far no work related to reliability modeling of Computer system has been reported in the literature of reliability using the concept of imperfect fault detection of hardware components.

In view of the above practical utility of computer systems, an effort has been made in the present work to obtain several performance measures of a computer system with independent hardware and software failures subject to imperfect fault detection of hardware components. For this purpose, a stochastic model is developed by using regenerative point technique. The following measures of system effectiveness are obtained:

- Transition Probabilities
- Mean Sojourn Times
- Reliability of the system
- Mean Time to System Failure (MTSF)
- Availability Analysis
- Busy Period Analysis of the Repairman
- Anticipated Number of arrivals by the Repairman
- Performance Analysis

2. Assumptions

- The system consists of two identical units- Initially one unit is operative and other is kept as spare in cold standby.
- A single repair facility is provided to the system for fault detection, repair, replacement and up-gradation purpose of the components.
- Upon hardware failure detector check the fault, if detector fails to detect the fault then repairman immediately replaces the failed hardware otherwise unit undergoes for repair.
- After failure of initial operative unit the cold standby becomes operative.
- If any software component fails then repairman up-grade the software with some up-gradation time.

The hardware and software failure time of the unit follows negative exponential distribution while the distributions of repair, fault detection and up-gradation time are taken as arbitrary with different probability density functions.

3. Notations

E	:	Collection of regenerative states
O	:	Operative unit
Cs	:	Cold standby
b /a	:	Chance of software/ hardware failure

λ_2/λ_1	:	Constant rate of software / hardware failure
p/q	:	Probability that fault in hardware is detected or not
FUr/FUR	:	Unit is under repair due to hardware failure / continuously under repair from previous state due to hardware failure
Fwr/FWR	:	Unit is waiting for repair due to hardware failure / continuously waiting for repair from previous state due to hardware failure
FUd/FUD	:	The unit is under fault detection / continuously under fault detection from previous state due to hardware failure
FWd / FWD	:	The unit is failed due to hardware and is waiting for detection/waiting for detection continuously from previous state
SUg / SUG	:	The unit is under up-gradation due to software failure/ continuously under up-gradation from previous state due to software failure
Swg / SWG	:	The unit is waiting for up-gradation due to software failure /continuously waiting for up-gradation from previous state due to software failure
H(t) / h(t)	:	cdf / pdf of hardware fault detection time
F(t) / f(t)	:	cdf / pdf of software up-gradation time
G(t) / g(t)	:	cdf / pdf of hardware repair time
m_{ij}	:	$m_{ij} = \int t dQ_{ij}(t) = -q_{ij}^{*\,'}(0)$. It represents the mean sojourn time in state S_i.
©/Ⓢ	:	Laplace convolution /Laplace-Stieltjes convolution
* /* *	:	Laplace Transform (LT)/ Laplace Steiltjes Transform (LST)

The probability density function for the transition of the system from one regenerative state S_i to another regenerative state S_j or to a failed state S_j either directly or via visiting to states S_k, S_l once in time (0,t] is denoted by respectively $q_{ij}(t) \& q_{ij,kl}(t)$. The cumulative density function for the same situations is denoted by $Q_{ij}(t) \& Q_{ij,kl}(t)$ respectively.

4. System Model Description

In this section, the two-unit cold standby system for a computer system is described. Through semi-Markov process and regenerative point technique, the recurrence equations are obtained for the analysis of state probabilities. The states of the system according semi-Markov process and regenerative point technique are as follows:

State 0: Initial state, one unit works, one unit in standby, and the system is working
State 1: Operative unit suffers due to software failure and under up-gradation, cold standby unit becomes operative; and the system is working
State 2: Operative unit suffers due to hardware failure and under fault detection, cold standby unit becomes operative and the system is working
State 3: Operative unit is continuously under operation, failed unit after fault detection undergoes for hardware repair and the system is operative
State 4: One unit is continuously under software up-gradation and other is waiting for software up-gradation and the system is failed
State 5: First failed unit is continuously under software up-gradation, second h/w failed unit is waiting for fault detection and the system failed
State 6: First h/w failed unit is continuously under fault detection, second s/w failed unit is waiting for s/w up-gradation and the system failed
State 7: First h/w failed unit after fault detection undergoes for h/w repair, second s/w failed unit is continuously waiting for s/w up-gradation and the system failed
State 8: First h/w failed unit is continuously under fault detection, second h/w failed unit is waiting for fault detection and the system failed

State 9: First h/w failed unit undergoes for h/w repair fault detection, second h/w failed unit continuously waiting for h/w fault detection from previous state and the system failed
State 10: First h/w failed unit is under repair continuously from previous state, second s/w failed unit is waiting for s/w up-gradation and the system failed
State 11: First h/w failed unit is under repair continuously from previous state, second h/w failed unit is waiting for h/w fault detection and the system failed
Where E = {S0, S1, S2, S3} is the set of regenerative states.

5. Transition Probabilities

Simple probabilistic arguments yield the following expressions for the non-zero elements

$$p_{ij} = Q_{ij}(\infty) = \int_0^\infty q_{ij}(t)dt \text{ as} \tag{1}$$

$p_{01} = \dfrac{b\lambda_2}{a\lambda_1 + b\lambda_2}$, $p_{11.4} = p_{14} = \dfrac{b\lambda_2}{a\lambda_1 + b\lambda_2}\left[1 - f^*(a\lambda_1 + b\lambda_2)\right]$, $p_{22.8,9} = \dfrac{qa\lambda_1}{a\lambda_1 + b\lambda_2}\left[1 - h^*(a\lambda_1 + b\lambda_2)\right]$,

$p_{10} = f^*(a\lambda_1 + b\lambda_2)$, $p_{12.5} = p_{15} = \dfrac{a\lambda_1}{a\lambda_1 + b\lambda_2}\left[1 - f^*(a\lambda_1 + b\lambda_2)\right]$, $p_{20} = qh^*(a\lambda_1 + b\lambda_2)$, $p_{67} = p_{89} = p$,

$p_{23} = ph^*(a\lambda_1 + b\lambda_2)$, $p_{26} = \dfrac{b\lambda_2}{a\lambda_1 + b\lambda_2}\left[1 - h^*(a\lambda_1 + b\lambda_2)\right]$, $p_{28} = \dfrac{a\lambda_1}{a\lambda_1 + b\lambda_2}\left[1 - h^*(a\lambda_1 + b\lambda_2)\right]$,

$p_{30} = g^*(a\lambda_1 + b\lambda_2)$, $p_{32.11} = p_{3.11} = \dfrac{a\lambda_1}{a\lambda_1 + b\lambda_2}\left[1 - g^*(a\lambda_1 + b\lambda_2)\right]$, $p_{41} = p_{52} = p_{71} = p_{92} = p_{10.1} = p_{11.2} = 1$,

$p_{31.10} = p_{3,10} = \dfrac{b\lambda_2}{a\lambda_1 + b\lambda_2}\left[1 - g^*(a\lambda_1 + b\lambda_2)\right]$, $p_{21.6} = \dfrac{qb\lambda_2}{a\lambda_1 + b\lambda_2}\left[1 - h^*(a\lambda_1 + b\lambda_2)\right]$, $p_{61} = p_{82} = q$,

$p_{22.8} = \dfrac{pa\lambda_1}{a\lambda_1 + b\lambda_2}\left[1 - h^*(a\lambda_1 + b\lambda_2)\right]$, $p_{21.6,7} = \dfrac{pb\lambda_2}{a\lambda_1 + b\lambda_2}\left[1 - h^*(a\lambda_1 + b\lambda_2)\right]$, $p_{02} = \dfrac{a\lambda_1}{a\lambda_1 + b\lambda_2}$

It can be easily verified that sum of all transition probabilities from each state equal to 1.

Mean Sojourn Times

The mean Sojourn time (μ_i) in state (S_i) by taking $h(t) = \beta e^{-\beta t}$, $f(t) = \theta e^{-\theta t}$ and $g(t) = \alpha e^{-\alpha t}$ is given by

$$\mu_0 = \frac{1}{(b\lambda_2 + a\lambda_1)},\ \mu_1 = \frac{1}{(b\lambda_2 + a\lambda_1 + \alpha)},\ \mu_2 = \frac{1}{(b\lambda_2 + a\lambda_1 + \beta)},\ \mu_3 = \frac{1}{(b\lambda_2 + a\lambda_1 + \theta)},\ \mu_1' = \frac{1}{\alpha},\ \mu_2' = \frac{1}{\beta},\ \mu_3' = \frac{1}{\theta} \tag{2}$$

6. Reliability and MTSF

In this section, we obtained the reliability and mean time to system failure (MTSF) of a computer system. The cumulative probability density function of the first passage time denoted by $\Delta_i(t)$ between $S_i, S_j \in E$. Here, on the basis of model description, we obtain the following recurrence relation for $\Delta_i(t)$ by assuming the down state S_j as an absorbing state, $\Delta_i(t) = \sum_j Q_{i,j}(t) ® \Delta_j(t) + \sum_k Q_{i,k}(t)$ (3)

where state $S_j \in E$ to which the given state $S_i \in E$ can transit and S_k is a down state to which the state S_i can transit directly. We solve the recurrence relation (3) by taking LST for $\tilde{\Delta}_0(s)$.

We have $$R^*(s) = \frac{1 - \tilde{\Delta}_0(s)}{s} \tag{4}$$

By taking the Laplace inverse transform of equation (4), we can obtain the reliability of the system. Now, the mean time to system failure (MTSF) is given by MTSF $= \lim_{s \to o} \frac{1-\tilde{\Delta}_0(s)}{s} = \frac{N_1}{D_1}$ (5)

where $N_1 = \mu_0 + p_{01}\mu_1 + p_{02}\mu_2 + p_{23}p_{02}\mu_3$ and $D_1 = 1 - p_{01}p_{10} - p_{02}p_{20} - p_{02}p_{23}p_{30}$

7. Availability Analysis

By probabilistic arguments

$M_0(t) = e^{-(a\lambda_1 + b\lambda_2)t}$, $M_1(t) = e^{-(a\lambda_1 + b\lambda_2)t}\overline{F(t)}$, $M_2(t) = e^{-(a\lambda_1 + b\lambda_2)t}\overline{H(t)}$ and $M_3(t) = e^{-(a\lambda_1 + b\lambda_2)t}\overline{G(t)}$

From the arguments used in the theory of regenerative processes, the point wise availabilities $A_i(t)$ are seen to satisfy the following recurrence relations $A_i(t) = M_i(t) + \sum_j q_{i,j}^{(n)} \copyright A_j(t)$ (6)

Where $S_j, S_i \in E$ and state S_i can transit to the successive state S_j through n transitions. Taking Laplace transformation of equation (6) and solving for $A_0^*(s)$ we get $A_0(\infty) = \lim_{s \to 0} s\,A_0^*(s) = \frac{N_2(0)}{D_2^{'}(0)}$

Where

$$D_2(s) = \begin{vmatrix} 1 & -q_{01}^*(s) & -q_{02}^*(s) & 0 \\ -q_{10}^*(s) & 1 - q_{11.4}^*(s) & -q_{12.5}^*(s) & 0 \\ -q_{20}^*(s) & -q_{21.6}^*(s) - q_{21.6,7}^*(s) & 1 - q_{22.8}^*(s) - q_{22.8,9}^*(s) & -q_{23}^*(s) \\ -q_{30}^*(s) & -q_{31.10}^*(s) & -q_{31.11}^*(s) & 1 \end{vmatrix}$$

and

$$N_2(s) = \begin{vmatrix} M_0^*(s) & -q_{01}^*(s) & -q_{02}^*(s) & 0 \\ M_1^*(s) & 1 - q_{11.4}^*(s) & -q_{12.5}^*(s) & 0 \\ M_2^*(s) & -q_{21.6}^*(s) - q_{21.6,7}^*(s) & 1 - q_{22.8}^*(s) - q_{22.8,9}^*(s) & -q_{23}^*(s) \\ M_3^*(s) & -q_{31.10}^*(s) & -q_{31.11}^*(s) & 1 \end{vmatrix}$$

8. Busy Period Analysis for Repairman

By probabilistic arguments, we get the following recurrence relations for $B_i(t)$

$$B_i(t) = K_i(t) + \sum_j q_{i,j}^{(n)}(t) \copyright B_j(t) \quad (7)$$

Where $S_j, S_i \in E$ and state S_i can transit to the successive state S_j through n transitions. The probability that the repairman remains busy in any state S_i due to hardware fault detecting, hardware repairing and software up-gradation of the unit up to time t without making any transition to any other regenerative state or returning to the same via one or more non-regenerative states is denoted by $K_i(t)$ and so $K_1(s)=e^{-(a\lambda_1+b\lambda_2)t}\overline{F}(t)$, $K_2(s)=e^{-(a\lambda_1+b\lambda_2)t}\overline{H}(t)$, $K_3(s)=e^{-(a\lambda_1+b\lambda_2)t}\overline{G}(t)$ The time for which repairman is busy in various repair activities is given by

$B_0(\infty)=\lim_{s\to 0} sB_0^*(s)=\frac{N_3(0)}{D_2'(0)}$ Where the value $B_0^*(s)$ is obtained by taking Laplace transformation of equation (7)

And
$$N_3(s)=\begin{vmatrix} 0 & -q_{01}^*(s) & -q_{02}^*(s) & 0 \\ W_1^*(s) & 1-q_{11.4}^*(s) & -q_{12.5}^*(s) & 0 \\ W_2^*(s) & -q_{21.6}^*(s)-q_{21.6,7}^*(s) & 1-q_{22.8}^*(s)-q_{22.8,9}^*(s) & -q_{23}^*(s) \\ W_3^*(s) & -q_{31.10}^*(s) & -q_{31.11}^*(s) & 1 \end{vmatrix}$$

And $D_2(s)$ is obtained already.

9. Anticipated Number of arrivals by the Repairman

By probabilistic arguments, we have following recursive relations for $N_i(t)$

$$N_i(t)=\sum_j Q_{i,j}^{(n)}(t)\circledR\left[\delta_j+N_j(t)\right] \tag{8}$$

Where $S_j, S_i \in E$ and state S_i can transit to state S_j while $\delta j=\begin{cases}1 & \text{if } S_j \in E \text{ where repairman starts anew job} \\ 0 & \text{otherwise}\end{cases}$. The anticipated number of arrivals per unit time by the repairman is given by $N_0(\infty)=\lim_{s\to 0} s\,\tilde{N}_0(s)=\frac{N_4(s)}{D_2'(s)}$

(9)

Where the value of $\tilde{N}_0(s)$ is obtained by taking the Laplace Steiltjes Transform of equation (8).

And
$$N_4(s)=\begin{vmatrix} Q_{01}^{**}(s)+Q_{02}^{**}(s) & -Q_{01}^{**}(s) & -Q_{02}^{**}(s) & 0 \\ 0 & 1-Q_{11.4}^{**}(s) & -Q_{12.5}^{**}(s) & 0 \\ 0 & -Q_{21.6}^{**}(s)-Q_{21.6,7}^{**}(s) & 1-Q_{22.8}^{**}(s)-Q_{22.8,9}^{**}(s) & -Q_{23}^{**}(s) \\ 0 & -Q_{31.10}^{**}(s) & -Q_{31.11}^{**}(s) & 1 \end{vmatrix}$$

and $D_2(s)$ is already obtained.

10. Performance Analysis

The performance of the system in the long run can be figured as follows $P=C_0A_0-C_1B_0-C_2N_0$ (10)
Where C_0, C_1 and C_2 in the above equation represents the gross income of the system, expenses on repairman due to his business in various repair activities and expenses for the visit by the repairman per unit time.

11. Numerical Study:

In the present study, the numerical results considering a particular case $g(t)=\theta e^{-\theta t}$, $h(t)=\beta e^{-\beta t}$ and $f(t)=\alpha e^{-\alpha t}$ are derived for some performance measures of a computer system of two identical units using the concept of imperfect fault detection. To highlight the importance of the study some graphs are also drawn with respect to software failure rate (λ_2) for mean time to system failure, availability and profit function. The tabular and graphical representation of the results is as follows:

Table: 1. Effect of imperfect fault detection and various repair policies on MTSF with respect to software failure rate (λ_2).

λ_2	α=.78,θ=1.05 β=0.42,a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045	α=1.02,θ=1.05 β=0.42, a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045	α=.78,θ=1.05 β=0.91, a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045	α=.78,θ=1.7 β=0.42, a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045
0.010	430.1070	435.7113	670.6158	462.5538
0.011	422.6180	428.6447	656.3276	454.2603
0.012	415.3392	421.7680	642.5067	446.2041
0.013	408.2625	415.0739	629.1327	438.3758
0.014	401.3800	408.5556	616.1864	430.7666
0.015	394.6844	402.2066	603.6495	423.3680
0.016	388.1687	396.0207	591.5046	416.1721
0.017	381.8262	389.9918	579.7354	409.1711
0.018	375.6504	384.1145	568.3263	402.3578
0.019	369.6353	378.3833	557.2626	395.7253
0.020	363.7751	372.7931	546.5303	389.2670

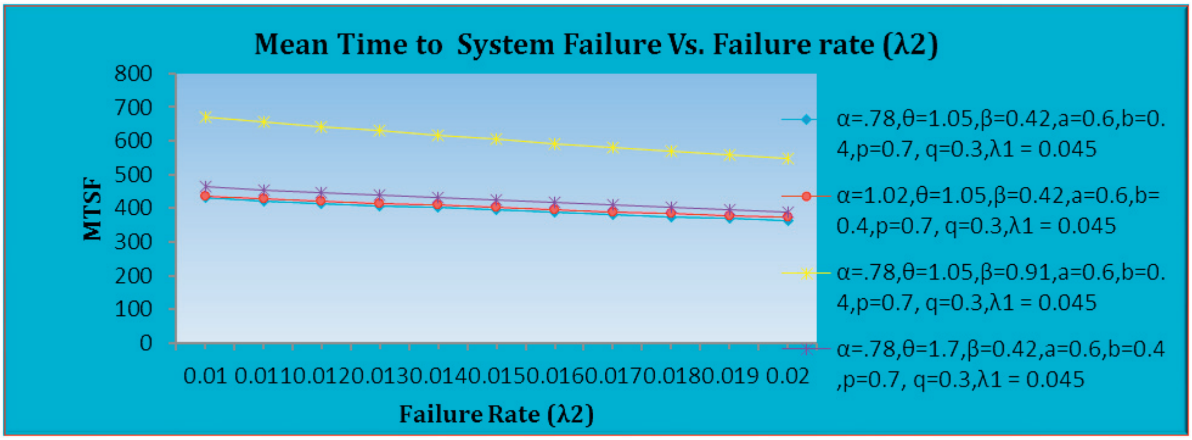

Fig.1: Mean Time to System Failure vs. Software Failure rate (λ2)

Table: 2. Effect of imperfect fault detection and various repair policies on steady state availability with respect to software failure rate (λ_2).

λ_2	α=.78,θ=1.05 β=0.42,a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045	α=1.02,θ=1.05 β=0.42, a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045	α=.78,θ=1.05 β=0.91, a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045	α=.78,θ=1.7 β=0.42, a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045
0.010	0.9949	0.9950	0.9983	0.9952
0.011	0.9949	0.9949	0.9983	0.9951
0.012	0.9948	0.9949	0.9982	0.9951
0.013	0.9947	0.9948	0.9982	0.9950
0.014	0.9946	0.9947	0.9982	0.9949
0.015	0.9945	0.9947	0.9981	0.9948
0.016	0.9944	0.9946	0.9981	0.9948
0.017	0.9944	0.9945	0.9980	0.9947
0.018	0.9943	0.9944	0.9980	0.9946

0.019	0.9942	0.9944	0.9980	0.9945
0.020	0.9941	0.9943	0.9979	0.9944

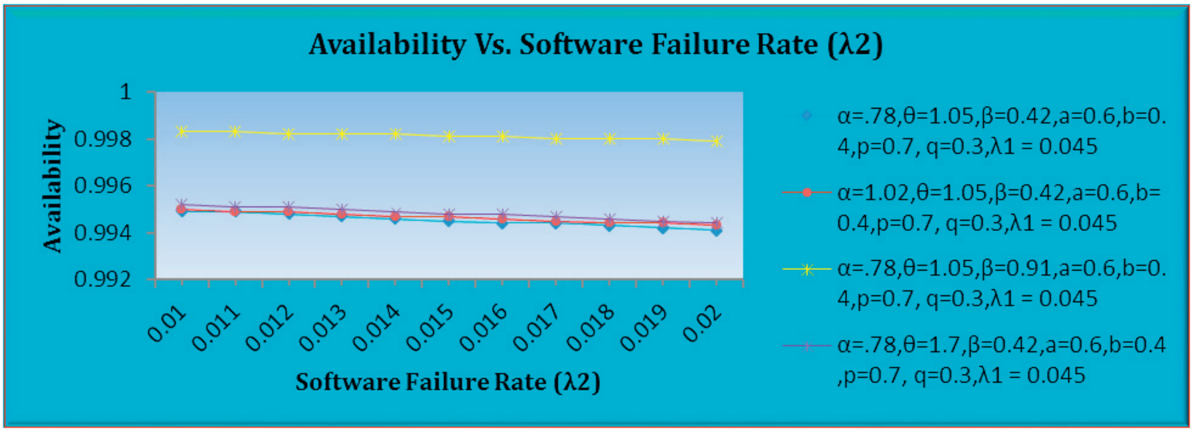

Fig. 2: Availability vs. Software Failure rate (λ2)

Table: 3. Effect of imperfect fault detection and various repair policies on profit function with respect to software failure rate (λ_2).

λ_2	α=.78,θ=1.05, β=0.42,a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045	α=1.02,θ=1.05 β=0.42, a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045	α=.78,θ=1.05 β=0.91, a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045	α=.78,θ=1.7 β=0.42, a=0.6, b=0.4,p=0.7, q=0.3, λ_1 = 0.045
0.010	4932.5	4935.4	4958.9	4935.7
0.011	4931.9	4934.9	4958.5	4935.1
0.012	4931.2	4934.3	4958.0	4934.5
0.013	4930.6	4933.8	4957.6	4933.9
0.014	4930.0	4933.2	4957.2	4933.3
0.015	4929.4	4932.7	4956.7	4932.7
0.016	4928.8	4932.2	4956.3	4932.1
0.017	4928.1	4931.6	4955.9	4931.5
0.018	4927.5	4931.1	4955.4	4930.8
0.019	4926.9	4930.5	4955.0	4930.2
0.020	4926.2	4930.0	4954.5	4929.6

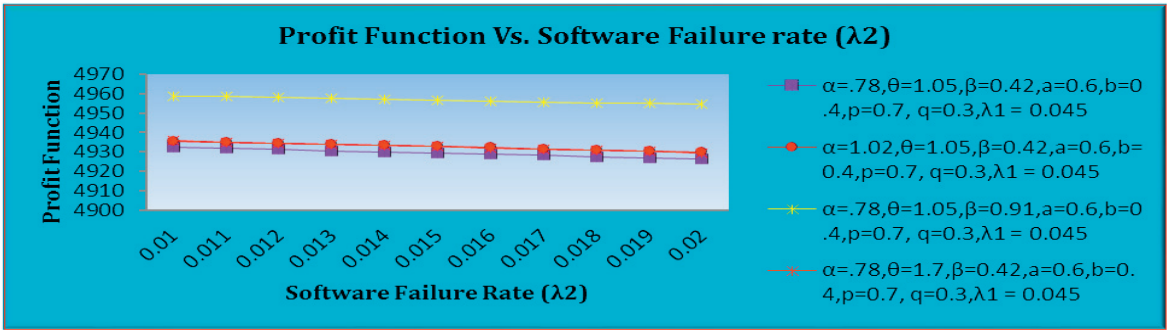

Fig. 3: Profit Function vs. Software Failure rate (λ2)

The numerical results for mean time to system failure (MTSF), availability and profit are drawn with respect to software failure rate (λ_2) for fixed values of other parameters including p=0.7 and q=0.3 as shown respectively in table 1-3 and figures 1-3 simultaneously. The graphical representation indicates that MTSF, availability and profit increases with the increase of hardware repair rate (θ), hardware fault detection rate (β) and software up gradation rate (α). But the value of these measures decrease with the increase of hardware and software failure rates.

Conclusion

On the basis of the numerical and graphical results obtained for a particular case, it is suggested that the reliability and profit of a system in which chances of h/w failure are high can be improved by

(i) By taking one more computer system in cold standby.
(ii) By increasing the fault detection rate.
(iii) By making up-gradation of the outdated s/w by new one.
(iv) By increasing the hardware repair rate.

References

1. Amari, S.V. , Dugan, J.B. and Misra, R.B(1999):"Optimal reliability of systems subject to imperfect fault-coverage, *IEEE Trans. on Reliability*, vol. 48, pp. 275-284.
2. Arnold, T. F. (1973): The concept of coverage and its effect on the reliability model of a repairable system, *IEEE Trans. on Computers*, vol. C-22, pp. 325-339.
3. Bouricius, W. G., Carter, W. C. and Schneider,P. R. (1969): "Reliability modeling techniques for self-repairing computer systems," *Proc.24th Ann. ACM.,Nat'l Conf*., pp 295-309.
4. Sahner, R., Trivedi, K. S. and Puliafito, A.(1995): Performance and Reliability Analysis of Computer Systems: An Example-Based Approach Using the SHARPE Software Package. Kluwer Academic Publishers, Boston, MA.
5. Friedman, M.A. and Tran, P. (1992): Reliability techniques for combined hardware / software systems. Proceedings of Annual Reliability and Maintainability Symposium, pp. 209-293.
6. Welke, S.R.; Johnson, B.W. and Aylar, J.H. (1995): Reliability modeling of hardware / software systems, IEEE Transactions on Reliability, Vol. 44, No. 3, pp. 413-418.
7. Lai, C.D.; Xie, M.; Poh, K.L.; Dai, Y.S. and Yang, P. (2002): A model for availability analysis of distributed software / hardware systems, Information and Software Technology, Vol. 44, pp. 343-350.
8. Malik, S. C. and Anand, J.(2010): Reliability and Economic Analysis of a Computer System with Independent Hardware and Software Failures, *Bulletin of Pure and Applied Sciences*,Vol.29 E (Math. & Stat.), No. 1, pp.141-153.
9. Malik, S. C. and Kumar, A.(2011): Profit Analysis of a Computer System with Priority to Software Replacement over Hardware Repair Subject to Maximum Operation and Repair Times, *International Journal of Engineering Science & Technology*, Vol.3, No. 10, pp. 7452- 7468.
10. Kumar, A. and Malik, S. C. (2012): Stochastic Modeling of a Computer System with Priority to PM over S/W Replacement Subject to Maximum Operation and Repair Times. *International Journal of Computer Applications*, Vol.43 (3), pp. 27-34.
11. Kumar, A. , Malik, S.C. and Barak, M.S. (2012): Reliability Modeling of a Computer System with Independent H/W and S/W Failures Subject to Maximum Operation and Repair Times, International Journal of Mathematical Achieves, Vol.3, No. 7, pp.2622-2630.
12. Kumar,A., Anand, J. and Malik, S.C.(2013): Stochastic Modeling of a computer system with priority to up-gradation of software over h/w repair activities, International Journal of Agricultural and Statistical Sciences, Vol. 9, No.1,pp.117-126.
13. Kumar, A. & Malik, S.C. (2014): Reliability modelling of a computer system with priority to H/w repair over replacement of H/w and up-gradation of S/w subject to MOT and MRT, Jordan Journal of Mechanical and Industrial Engineering, Vol.8 (4), pp. 233-241.
14. Malik, S.C. and Munday, V.J. (2014): Stochastic modeling of computer systems with hardware redundancy. International journal of computer applications, Vol. 89(7), pp. 26-30.